Review

# Defining the relationship between arm and leg blood pressure readings: a systematic review and meta-analysis

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**Objectives:** To define the relationship between arm and leg blood pressure (BP) to inform the interpretation of leg BP readings in routine clinical practice where arm readings are not available.

**Methods:** Systematic review of all existing studies comparing arm and leg BP measurements. A search strategy was designed in MEDLINE and adapted to be run across six further databases. Articles were deemed eligible for inclusion if they measured and reported arm and leg BP taken in the supine position and/or the difference between the two. Mean values for arm–leg BP difference and measures of precision [95% confidence intervals (CIs) or SD] were extracted and entered into a random-effects meta-analysis.

**Results:** A total of 887 articles were screened and 44 were included in the descriptive analyses, including 9771 patients. In the general population, ankle SBP was 17.0 mmHg (95% CI 15.4–21.3 mmHg) higher than arm BP in the supine position. For DBP, there was no difference between arm and ankle BP (−0.3 mmHg, 95% CI −1.5–1.0 mmHg). In patients with vascular disease, SBP was −33.3 mmHg (95% CI −59.1 to −7.6 mmHg) lower in the ankle compared with the arm.

**Conclusion:** This is the first review to provide empirical data defining the difference between BP in the arm and leg in the general population. Findings suggest a diagnostic threshold of 155/90 mmHg could be used for diagnosing hypertension when only ankle measurements are available in routine practice.

**Keywords:** ankle blood pressure, arm–leg blood pressure difference, calf blood pressure, diagnostic threshold, hypertension, meta-regression

**Abbreviations:** BP, blood pressure; CI, confidence interval; CVD, cardiovascular disease

## INTRODUCTION

Blood pressure (BP) is normally measured on the upper arm [1], but occasionally this is not possible for a variety of reasons that prevent placement of the cuff, for example, the presence of fractures, wounds, vascular access devices, morbid obesity, surgical procedures, limb deformities and amputations. In addition, BP measurement may be inaccurate in the presence of bilateral subclavian artery stenosis, such as that which can occur with Takayasu's arteritis [2] or atherosclerosis [3]. In these circumstances, measurement of BP on the leg may be necessary but currently, there are no clinical guidelines to guide measurement technique or interpretation.

A number of previous studies have compared BP readings made in the leg to those in the upper arm [4–6]. However, these studies have examined different populations using varying measurement techniques, so it is unclear what standard BP difference between upper and lower limbs should be expected. It is also unclear how diagnostic and treatment thresholds should be adjusted when leg BP measurements are relied upon to guide treatment. One previous study has suggested that in the absence of vascular disease, an elevated ankle SBP of more than 175 mmHg should be considered abnormal, based on the risk of cardiovascular disease (CVD) [7]. However, it is not clear whether this is equivalent to the 140 mmHg threshold used for brachial BP [1].

The current study aimed to systematically review the literature and summarize existing evidence describing appropriate methods of leg BP measurement and the relationship between arm and leg BP, to provide recommendations on how leg measurements should be interpreted in routine clinical practice.

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# METHODS

## Design

Systematic review aiming to capture all existing studies comparing arm and leg BP measurements in the same patients. Mean values for arm–leg BP difference and measures of precision [95% confidence intervals (CIs), SD or 95% limits of agreement] were extracted and entered into a random-effects meta-analysis.

## Search strategy

A scoping search was carried out to identify background literature and provide an estimate of the volume of literature on the topic. The search strategy was originally designed in the MEDLINE database (for search terms, see Appendix, http://links.lww.com/HJH/B26) and was adapted to be run across the following databases: CINAHL (EBSCO), The Cochrane (Wiley) CENTRAL Register of Controlled Trials, EMBASE (Ovid), MEDLINE In Process (Ovid), Science Citation Index – Expanded & Conference Proceedings Citation Index – Science and the ZETOC (Mimas) database.

No date limits were applied to the searches, although animal studies, letters, comments and review articles were excluded. Furthermore, it was not possible to assess non-English language articles (due to resource limitations). In addition to searches of electronic databases, reference lists of included studies were checked to identify any further relevant articles. Searches were conducted in August 2016.

## Selection criteria

All studies were screened by at least two reviewers (J.P.S., A.A., M.F. or B.F.) at each stage of screening. Disagreements were resolved with a third reviewer. Articles were selected for data extraction based on the following inclusion criteria:

(1) Measure arm BP.
(2) Measure leg BP.
(3) Estimate the difference between arm and leg BP and provide a measure of precision for this estimate (95% CIs, SD, 95% limits of agreement).
(4) Readings taken either simultaneously or sequentially within the same clinic visit.
(5) Cross-sectional, cohort or randomized controlled trial study design.
(6) Describe method of arm and leg BP measurement in sufficient detail that it could be repeated.
(7) Include primary data.

Studies were excluded from data extraction if they:

(1) Examined assessments made in a nonclinical or pharmacy setting.
(2) Studied patients aged less than 18 years or who were pregnant.

## Data collection

Data were extracted by four reviewers (J.P.S., A.A., B.F. and L.P.) who all initially examined 10% of included articles and resolved discrepancies prior to commencing data extraction in the rest of the studies. Data were extracted using a predefined data extraction sheet (see online Appendix, http://links.lww.com/HJH/B26). Data relating to the definition and method of measurement of arm and leg BP, along with mean values for each, mean difference and an estimate of precision were extracted. In addition, any information about the setting and sample population were recorded, including patient demographics, prescribed medication and history of CVD events or risk factors.

## Assessment of methodological quality

As part of the data extraction, the methodological quality and risk of bias of individual studies was assessed. This quality assessment covered domains of selection bias, detection bias, accuracy of measurement, analysis and confounding using a combination of questions from the QUADAS-2 [8] and Critical Appraisal Skills Programme [9] checklists for assessment of cohort studies. For sensitivity analyses, studies fulfilling the majority of quality domains ($\geq$4 domains) were deemed high quality. Those with unclear reporting or failing to fulfil the majority of quality domains were deemed low or moderate quality.

## Outcome measures

The primary outcome of this review was to compare the mean difference between BP measured in the arm and leg in the supine position. Leg BP was defined by readings taken in the ankle, calf or thigh and readings from each location were considered separately. Secondary outcomes were to define this difference in population subgroups (patients with high CVD risk or history of vascular disease) and by method of measurement (sequential/simultaneous), arm BP level and age. Further, this review aimed to describe the different approaches to measuring leg BP and arm/leg BP difference to inform future clinical guidance on this procedure.

## Data synthesis

Descriptive statistics were used to summarize included study characteristics. BP measurement techniques were described qualitatively. The primary outcome was examined in a random-effects meta-analysis of mean arm–leg BP difference, considering comparisons with ankle, calf and thigh readings separately. Where mean difference was not published, it was estimated from the mean and SD of values in the arm and leg. Analyses focused on measurements taken in the supine position. Where the position of measurement was unclear, it was assumed that readings were taken in the supine position and comparisons were included in the analysis. Heterogeneity was summarized using I-squared statistics.

Data are presented according to measurement technique where feasible. Subgroup analyses were conducted focusing on populations at high risk of CVD, those with a history of vascular disease and by measurement device to explore possible sources of heterogeneity. Meta-regression was undertaken to examine the possible association between arm–ankle BP difference and mean arm BP and age.

Sensitivity analyses were conducted using a fixed effects model to examine the assumption of random effect in the primary analysis. Further sensitivity analyses explored:



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(1) the impact of study quality on the primary outcome (with moderate and low-quality studies excluded).
(2) excluding studies which did not measure both SBP and DBP in the same patients or those which did not use either auscultation or a validated upper arm device.
(3) the difference in arm–ankle BP as a percentage of the arm BP (arm–ankle BP difference divided by arm BP).

Screening was conducted using Covidence (Vertitas Health Innovation Ltd, Melbourne, Victoria, Australia) and all analyses were undertaken in STATA version 13.1 (MP parallel edition; StataCorp, College Station, Texas, USA). Data are presented as proportions of the total study population, means with SD or 95% CIs unless otherwise stated.

# RESULTS

## Description of included studies

A total of 887 articles were screened after exclusion of duplicates (Fig. 1). Of the 340 full text articles assessed for eligibility, 44 were included in the final descriptive analyses. Included studies examined a total of 9771 patients, just under half were female (46%) and the mean age ranged from 30 to 74 years (Table 1). Populations were

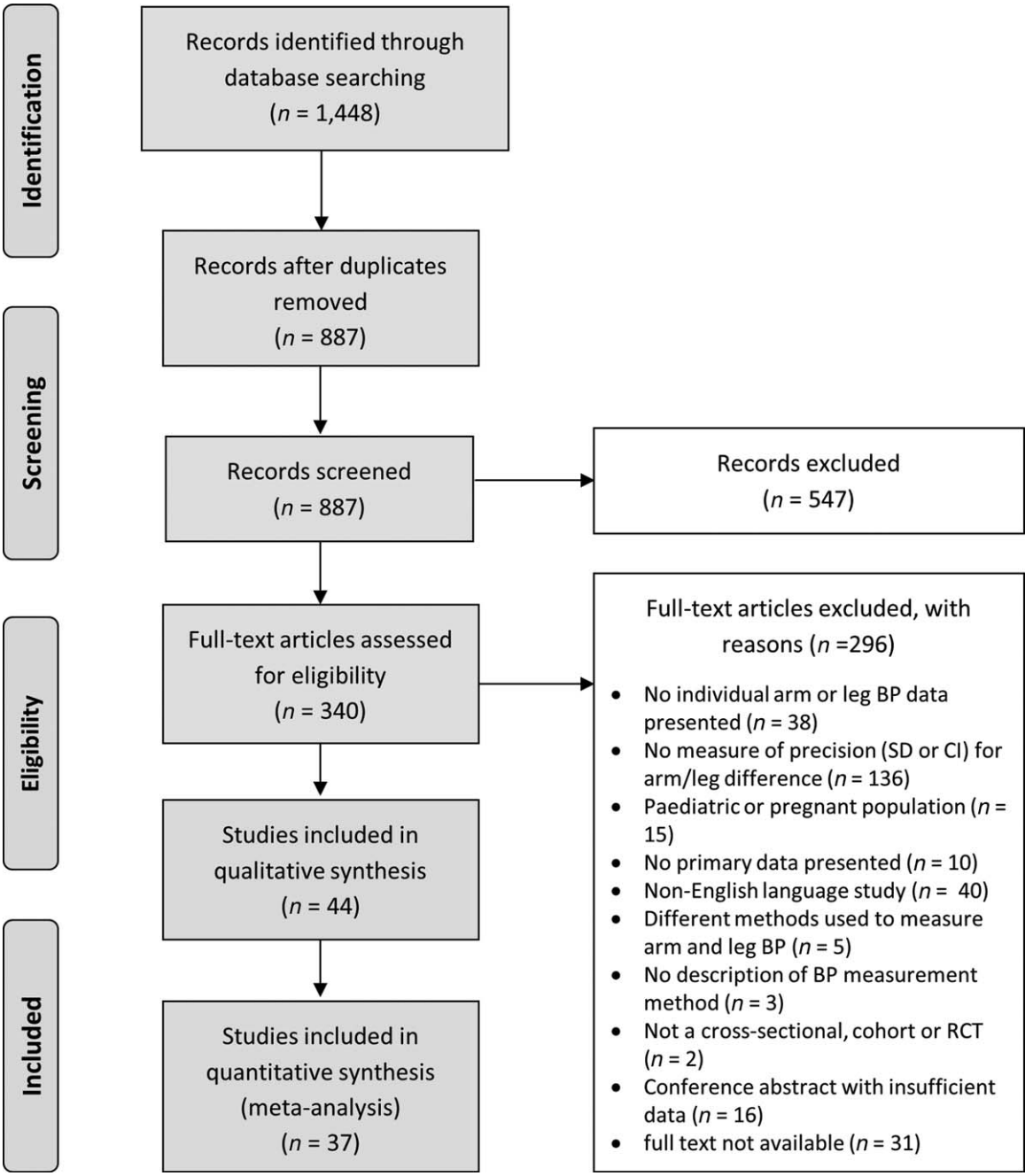
Identification
Screening
Eligibility
Included
Records identified through database searching (n = 1,448)
Records after duplicates removed (n = 887)
Records screened (n = 887)
Records excluded (n = 547)
Full-text articles assessed for eligibility (n = 340)
Full-text articles excluded, with reasons (n =296)
No individual arm or leg BP data presented (n = 38)
No measure of precision (SD or CI) for arm/leg difference (n = 136)
Paediatric or pregnant population (n = 15)
No primary data presented (n = 10)
Non-English language study (n = 40)
Different methods used to measure arm and leg BP (n = 5)
No description of BP measurement method (n = 3)
Not a cross-sectional, cohort or RCT (n = 2)
Conference abstract with insufficient data (n = 16)
full text not available (n = 31)
Studies included in qualitative synthesis (n = 44)
Studies included in quantitative synthesis (meta-analysis) (n = 37)

**FIGURE 1** Selection of studies. BP, blood pressure; CI, confidence intervals; RCT, randomized controlled trial



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**TABLE 1. Participant characteristics in included studies**

| Author, year (subpopulation) | Total pop., *n* | Sex, *n*, % female | Age (years, mean ± SD) | Hypertensive, *n* (%) | Anithypertensive medication, *n* (%) | History of CVD, *n* (%) | Diabetes, *n* % | CKD, *n* (%) | BMI (kg/m$^2$, mean ± SD) | ABI (mean) |
|---|---|---|---|---|---|---|---|---|---|---|
| Allison, 1973 (SVD) [10] | 78 | – | 55 ± 14 | – | – | – | – | – | – | 0.81 |
| Allison, 1973 (VOD) [10] | 22 | – | 54 ± 19 | – | – | 22 (100%) | – | – | – | 0.73 |
| Arveschoug, 2008 (middle-aged patients) [11] | 14 | 12 (86%) | 51 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | – | – | 1.22 |
| Arveschoug, 2008 (elderly patients) [11] | 31 | 25 (81%) | 71 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | – | – | 1.17 |
| Atsma, 2005 [12] | 320 | 320 (100%) | 66 ± 6 | 110 (34%) | – | 3 (1%) | 23 (7%) | – | – | – |
| Banner, 1991 [13] | 6 | – | – | – | – | – | – | – | – | 1.21 |
| Barani, 2005 [14] | 198 | 99 (50%) | 74 ± 10 | – | – | 198 (100) | 100 (51%) | – | 25.1 ± 4.7 | 0.30 |
| Bell, 1973 [15] | 30 | 0 (0%) | (13–55) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | – | – |
| Bollinger, 1976 (AOD – intraarterial readings) [16] | 13 | 3 (23%) | 58 ± 15 | – | – | – | – | – | – | 0.67 |
| Bollinger, 1976 (AOD – indirect readings) [16] | 11 | 3 (27%) | 60 ± 14 | – | – | – | – | – | – | 0.67 |
| Bollinger, 1976 (healthy – intraarterial readings) [16] | 13 | 0 (0%) | 39 ± 11 | – | – | – | – | – | – | 1.15 |
| Bollinger, 1976 (healthy – indirect readings) [16] | 3 | 0 (0%) | 27 ± 4 | – | – | – | – | – | – | 1.15 |
| Cao, 2014 [4] | 414 | 214 (52%) | 61 ± 13 | 414 (100%) | 414 (100%) | – | – | – | – | 1.11 |
| Engvall, 1989 [17] | 19 | 9 (47%) | 34 | 0 (0%) | – | 0 (0%) | – | – | – | 1.18 |
| Engvall, 1995 [18] | 22 | 9 (41%) | 33 | 22 (100%) | – | – | – | – | – | – |
| Freitas, 2014 (normotensive patients) [19] | 50 | 47 (94%) | 41 ± 2 | 0 (0%) | – | – | 0 (0%) | – | 28.1 ± 0.76 | 1.15 |
| Freitas, 2014 (hypertensive patients) [19] | 50 | 37 (74%) | 58 ± 2 | 50 (100%) | – | – | 0 (0%) | – | 31.7 ± 1.1 | 1.12 |
| Freitas, 2014 (white-coat hypertensive patients) [19] | 35 | 30 (86%) | 54 ± 3 | 35 (100%) | – | – | 0 (0%) | – | 30.6 ± 1.2 | 1.13 |
| Gardner, 1998 [20] | 50 | 3 (6%) | 69 ± 7 | 29 (58%) | – | 50 (100%) | 11 (22%) | – | 27.6 ± 4.3 | 0.67 |
| Gemignani, 2012a [21] | 197 | 117 (59%) | 52 ± 1 | 75 (38%) | – | – | 28 (14%) | – | 26.4 ± 0.3 | – |
| Gemignani, 2012b [22] | 130 | 77 (59%) | 34 ± 1 | – | 0 (0%) | – | – | – | 24.8 ± 0.4 | – |
| Goldstein, 2014 [23] | 201 | 63 (31%) | 34 | – | – | 0 (0%) | 0 (0%) | – | 25.6 | 1.11 |
| Goldthorp, 1986 [24] | 30 | – | (23–76) | – | – | – | – | – | – | – |
| Gong, 2015 [5] | 948 | – | 48 ± 19 | 0 (0%) | – | 0 (0%) | 0 (0%) | – | 22.9 ± 3.5 | 1.15 |
| Grenon, 2009 [25] | 12 | 4 (33%) | 26 ± 1 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 22.3 | 1.17 |
| Instebo, 2004 (arm–leg difference <1 mmHg) [26] | 13 | 6 (46%) | 26 ± 7 | 0 (0%) | – | – | – | – | 22.4 | – |
| Instebo, 2004 (arm–leg difference 1–20 mmHg) [26] | 12 | 5 (42%) | 24 ± 9 | 12 (100%) | – | – | – | – | 22.9 | – |
| Instebo, 2004 (arm–leg difference >20 mmHg) [26] | 16 | 5 (31%) | 24 ± 7 | 16 (100%) | – | – | – | – | 24 | – |
| Koay, 1985 [27] | 15 | 5 (33%) | 45 | – | – | – | – | – | – | 1.11 |
| Lee, 1996 [28] | 110 | 1 (1%) | 69 | – | – | 30 (27%) | 53 (48%) | – | – | 0.92 |
| Lee, 2011 [29] | 60 | 25 (42%) | 43 (20–78) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | – | – | 1.14 |
| Maldonado, 2008 [30] | 224 | 0 (0%) | 17.1 ± 5.6 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 22.3 ± 13.8 | 1.18 |
| Malhotra, 2002 [31] | 41 | 18 (44%) | 52 ± 14 | 19 (46%) | – | – | – | – | 25.1 | 1.72 |
| Martins, 2010 [32] | 75 | 36 (48%) | 60 ± 10.2 | 75 (100%) | >50 (>50%) | – | 20 (27%) | 0 (0%) | 29.8 ± 4.9 | 1.20 |
| Moore, 2008 [6] | 100 | 65 (65%) | (20–64) | 0 (0%) | 0 (0%) | 0 (0%) | – | – | – | – |
| Oguanobi, 2012 (sickle cell anaemia patients) [33] | 62 | 31 (50%) | 28.3 ± 5.6 | – | – | – | – | – | 20.5 ± 2.7 | 0.88 |
| Oguanobi, 2012 (healthy controls) [33] | 62 | 31 (50%) | 28.4 ± 5.9 | – | – | – | – | – | 23.9 ± 3.2 | 1.03 |
| Okada, 2013 [34] | 314 | 121 (39%) | 66.2 ± 8.5 | – | 183 (58%) | – | 314 (100%) | – | 23.6 ± 3.7 | 1.11 |
| Pan, 2007 [35] | 946 | 481 (51%) | 44.9 | 274 (29%) | 61 (6.5%) | – | – | – | 22.1 | – |
| Quong, 2016 [36] | 73 | 31 (42%) | 24.3 ± 2.0 | – | – | – | – | – | 21.9 | 1.09 |
| Rahiala, 2001 [37] | 20 | 20 (100%) | 18.8 ± 0.9 | – | – | – | – | – | – | 1.10 |
| Richart, 2009 [38] | 105 | 55 (52%) | 56.5 | 26 (25%) | – | – | – | – | 26.2 | 1.13 |
| Sahli, 2004 [39] | 437 | 199 (46%) | 54 | 87 (20%) | – | – | 300 (69%) | – | 25.5 | – |
| Sareen, 2012 [40] | 250 | – | – | – | – | – | – | – | – | – |
| Sheng, 2013 [41] | 3133 | 1750 (56%) | 69 | – | 1215 (39%) | – | 285 (9%) | – | 23.6 | – |
| Siggaard-Andersen, 1972 [42] | 34 | 4 (12%) | 55 | – | – | – | – | – | – | – |
| Su, 2007 [43] | 38 | 8 (21%) | 58.7 ± 14 | 27 (71%) | – | – | – | – | – | – |
| Swan, 2003 (coarctation patients) [44] | 45 | 17 (38%) | 29.8 ± 11.0 | 8 (18%) | 8 (18) | 45 (100%) | – | – | 30.3 ± 14.8 | – |
| Swan, 2003 (controls) [44] | 33 | 13 (39%) | 30.6 | 0 (0%) | 0 (0%) | 0 (0%) | – | – | 31.6 ± 12.6 | – |
| Thulesius, 1978 (controls) [45] | 18 | – | 52 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | – | – | – |
| Thulesius, 1978 (patients with minor PAI) [45] | 14 | – | 60 | – | – | 14 (100%) | – | – | – | – |
| Thulesius, 1978 (patients with severe PAI) [45] | 58 | – | 60 | – | – | 14 (100%) | – | – | – | – |
| Vriend, 2005 [46] | 73 | 30 (41%) | 29.8 | 33 (45%) | 9 (12%) | 33 (45%) | – | – | 23.4 ± 3.3 | – |
| Weatherley, 2006 [47] | 119 | 70 (59%) | 55.0 ± 5.7 | 43 (36) | – | – | 13 (11%) | – | 27.0 ± 4.78 | – |
| Wilkes, 2004 [48] | 45 | 23 (51%) | 55 | 0 (0%) | 0 (0%) | – | – | – | 27.3 | 1.18 |
| Williamson, 1921 [49] | 15 | 1 (7%) | 43.0 ± 10.6 | – | – | 15 (100%) | – | – | – | – |
| Yeragani, 2007 (controls) [50] | 22 | 7 (32%) | 47 ± 15 | 0 (0%) | 0 (0%) | 0 (0%) | – | – | 24 | 1.06 |
| Yeragani, 2007 (participants with anxiety) [50] | 26 | 7 (27%) | 44 ± 13 | 0 (0%) | 0 (0%) | 0 (0%) | – | – | 26 | 1.07 |
| Yeragani, 2007 (patients with CVD) [50] | 72 | 19 (26%) | 59 ± 13 | 21 (29%) | 7 (10%) | 72 (100%) | – | – | 27 | 1.07 |

ABI, ankle–brachial index; AOD, arterial occlusive disease; CKD, chronic kidney disease; CVD, cardiovascular disease; PAI, peripheral arterial insufficiency; SVD, small vessel disease; VOD, vascular occlusive disease.



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**TABLE 2. Methodological quality of included studies**

| Reference | Patient selection | | | Outcome measurement | Analysis | Confounding | |
|---|---|---|---|---|---|---|---|
| | Was selection of patients appropriate? | Did the study avoid inappropriate exclusions? | Was the study sample representative of the intended population? | Is the outcome variable measured appropriately? | Was the arm–leg BP difference the primary focus of the study? | Were all important confounding factors identified? | Overall quality rating[a] |
| Allison *et al.* [10] | Unclear | Unclear | Unclear | Yes | Yes | Unclear | Low |
| Arveschoug *et al.* [11] | Unclear | Yes | Yes | Yes | Yes | Yes | High |
| Atsma *et al.* [12] | Unclear | Yes | Unclear | Yes | Yes | Yes | High |
| Banner and Gravenstein [13] | Unclear | Unclear | Unclear | Yes | No | Unclear | Low |
| Barani *et al.* [14] | Yes | Yes | Yes | Unclear | No | Yes | High |
| Bell *et al.* [15] | Unclear | No | No | Yes | Yes | Unclear | Low |
| Bollinger *et al.* [16] | Unclear | Yes | Unclear | Yes | No | Yes | Moderate |
| Cao *et al.* [4] | Yes | No | Yes | Yes | Yes | Unclear | High |
| Engvall *et al.* [17] | Unclear | Unclear | Unclear | Yes | Yes | Unclear | Low |
| Engvall *et al.* [18] | Unclear | Unclear | Unclear | Yes | Yes | Unclear | Low |
| Freitas *et al.* [19] | No | Yes | Unclear | Yes | No | Yes | Moderate |
| Gardner and Montgomery [20] | Unclear | Yes | Unclear | Yes | No | Yes | Moderate |
| Gemignani *et al.* [21] | Unclear | Yes | Unclear | Yes | No | Yes | Moderate |
| Gemignani *et al.* [22] | Unclear | Yes | Unclear | Yes | Yes | Yes | High |
| Goldstein *et al.* [23] | Unclear | Yes | Unclear | Yes | Yes | Yes | High |
| Goldthorp *et al.* [24] | Unclear | Unclear | Unclear | Yes | Yes | Unclear | Low |
| Gong *et al.* [5] | Unclear | Yes | Unclear | Yes | Yes | Unclear | Moderate |
| Grenon *et al.* [25] | Unclear | Yes | Unclear | Yes | Yes | Yes | High |
| Instebo *et al.* [26] | Unclear | Yes | Unclear | Yes | No | No | Low |
| Koay and Chin [27] | Yes | Yes | Unclear | Yes | Yes | Yes | High |
| Lee *et al.* [28] | Yes | Unclear | Yes | Yes | No | Unclear | Moderate |
| Lee *et al.* [29] | Unclear | Yes | Unclear | Yes | No | Yes | Moderate |
| Maldonado *et al.* [30] | Unclear | Unclear | Unclear | Yes | Yes | Unclear | Low |
| Malhotra *et al.* [31] | Unclear | Unclear | Unclear | Yes | Yes | Unclear | Low |
| Martins *et al.* [32] | Yes | Yes | Yes | Yes | No | Yes | High |
| Moore *et al.* [6] | Unclear | Yes | Unclear | Yes | Yes | Yes | High |
| Oguanobi *et al.* [33] | Unclear | Unclear | Unclear | Yes | Yes | Unclear | Low |
| Okada *et al.* [34] | Yes | Yes | Unclear | Yes | Yes | Unclear | High |
| Pan *et al.* [35] | Yes | Yes | Unclear | Yes | Yes | Unclear | High |
| Quong *et al.* [36] | Unclear | Yes | Unclear | Yes | Yes | Unclear | Moderate |
| Rahiala *et al.* [37] | Unclear | unclear | Unclear | Yes | Yes | Unclear | Low |
| Richart *et al.* [38] | Yes | Unclear | Unclear | Yes | Yes | Unclear | Moderate |
| Sahli *et al.* [39] | Unclear | Yes | Unclear | Yes | Yes | Yes | High |
| Sareen *et al.* [40] | Unclear | Yes | Unclear | Yes | Yes | Yes | High |
| Sheng *et al.* [41] | Yes | Yes | Unclear | Yes | Yes | Yes | High |
| Siggaard-Andersen *et al.* [42] | Unclear | Unclear | Unclear | Yes | Yes | Unclear | Low |
| Su *et al.* [43] | Yes | Yes | Unclear | Unclear | Yes | Yes | High |
| Swan *et al.* [44] | Yes | Yes | No | Unclear | Yes | Unclear | Moderate |
| Thulesius [45] | Unclear | Unclear | Unclear | Unclear | Yes | No | Low |
| Vriend *et al.* [46] | Yes | Unclear | Yes | Unclear | Yes | Yes | High |
| Weatherley *et al.* [47] | No | Unclear | Yes | Yes | Yes | Unclear | Moderate |
| Wilkes and DiPalma [48] | Yes | No | No | Yes | Yes | Yes | High |
| Williamson [49] | Unclear | Unclear | Unclear | Unclear | Yes | Unclear | Low |
| Yeragani *et al.* [50] | Yes | Yes | Unclear | Unclear | No | Yes | Moderate |

[a]High quality = 4 or more quality domains present; moderate = 3 quality domains present; low = 2 or less quality domains present.

heterogeneous with some including patients with a history of hypertension, diabetes, chronic kidney disease and CVD (Table 1), conducted in a variety of settings (eTable 1, online Appendix, http://links.lww.com/HJH/B26).

The methodological quality of included studies was mixed (Table 2). Most studies avoided inappropriate exclusions and measured the outcome variables appropriately. However, the method of participant selection was rarely described and it was difficult to judge whether the intended population had been captured in the majority of studies.

There was no consistent method or standardized approach for measuring the arm–leg BP difference. Studies compared BP measured over the brachial artery to readings taken on the ankle, calf, foot or thigh, using a variety of measurement techniques and devices (eTable 3, http://links.lww.com/HJH/B26). These included standard auscultatory and oscillometric sphygmomanometers, Doppler probes and mercury strain-gauge plethysmography. Most studies ($n = 35/44$) clearly stated that readings were taken with patients in the supine position and simultaneous readings were more common than sequential readings (18 studies vs. 16 studies (10 studies did not state the order of readings); eTables 2 and 3, online Appendix, http://links.lww.com/HJH/B26).

## Primary outcome

### Ankle–arm difference in a supine position

In the general population, ankle SBP was 17.0 mmHg (95% CI 15.4–21.3 mmHg) higher than arm BP, and this difference was consistent whether BP was measured



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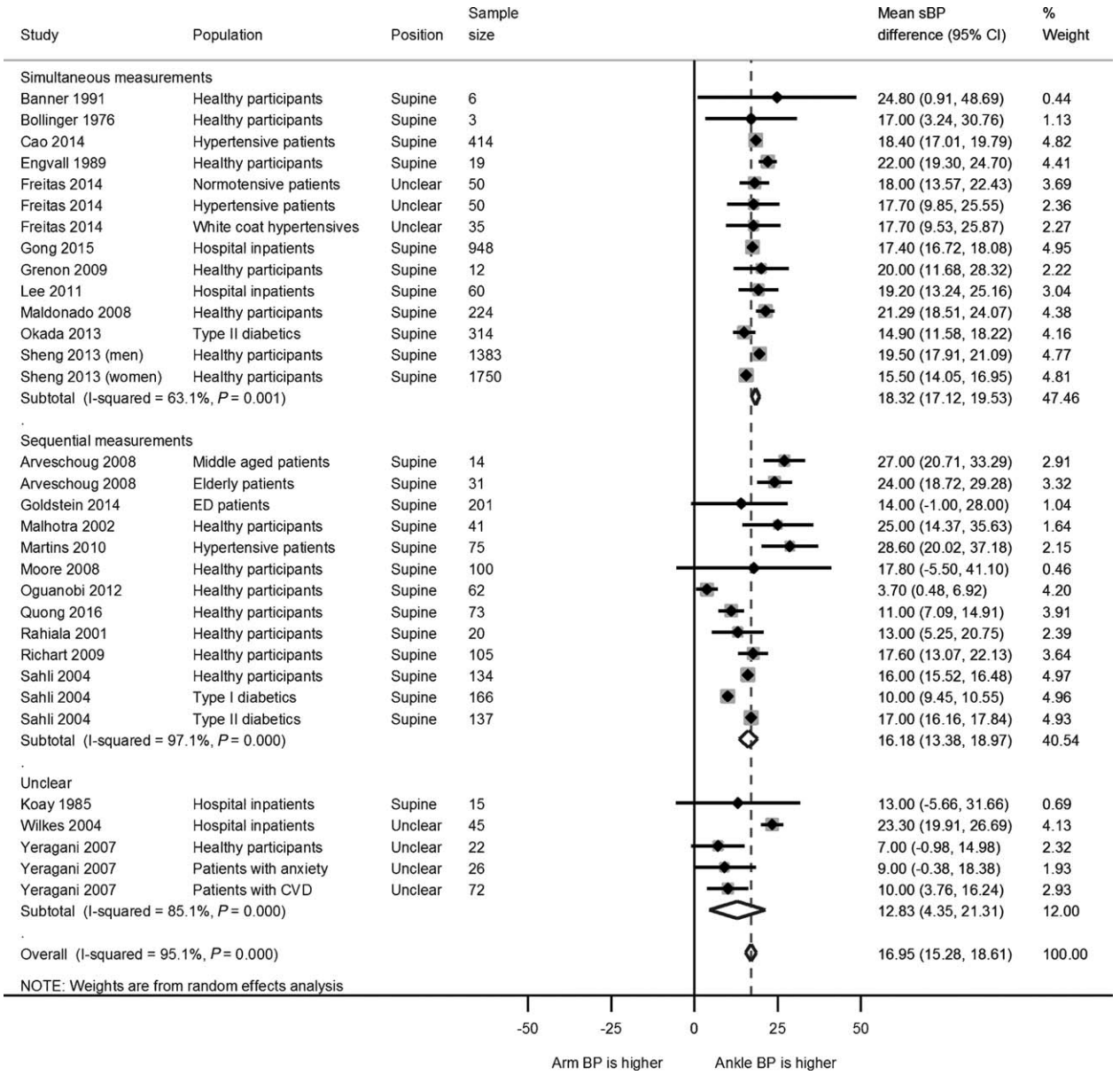
Study
Population
Position
Sample size
Mean sBP difference (95% CI)
% Weight
Simultaneous measurements
Banner 1991 Healthy participants Supine 6 24.80 (0.91, 48.69) 0.44
Bollinger 1976 Healthy participants Supine 3 17.00 (3.24, 30.76) 1.13
Cao 2014 Hypertensive patients Supine 414 18.40 (17.01, 19.79) 4.82
Engvall 1989 Healthy participants Supine 19 22.00 (19.30, 24.70) 4.41
Freitas 2014 Normotensive patients Unclear 50 18.00 (13.57, 22.43) 3.69
Freitas 2014 Hypertensive patients Unclear 50 17.70 (9.85, 25.55) 2.36
Freitas 2014 White coat hypertensives Unclear 35 17.70 (9.53, 25.87) 2.27
Gong 2015 Hospital inpatients Supine 948 17.40 (16.72, 18.08) 4.95
Grenon 2009 Healthy participants Supine 12 20.00 (11.68, 28.32) 2.22
Lee 2011 Hospital inpatients Supine 60 19.20 (13.24, 25.16) 3.04
Maldonado 2008 Healthy participants Supine 224 21.29 (18.51, 24.07) 4.38
Okada 2013 Type II diabetics Supine 314 14.90 (11.58, 18.22) 4.16
Sheng 2013 (men) Healthy participants Supine 1383 19.50 (17.91, 21.09) 4.77
Sheng 2013 (women) Healthy participants Supine 1750 15.50 (14.05, 16.95) 4.81
Subtotal (I-squared = 63.1%, P = 0.001) 18.32 (17.12, 19.53) 47.46
Sequential measurements
Arveschoug 2008 Middle aged patients Supine 14 27.00 (20.71, 33.29) 2.91
Arveschoug 2008 Elderly patients Supine 31 24.00 (18.72, 29.28) 3.32
Goldstein 2014 ED patients Supine 201 14.00 (-1.00, 28.00) 1.04
Malhotra 2002 Healthy participants Supine 41 25.00 (14.37, 35.63) 1.64
Martins 2010 Hypertensive patients Supine 75 28.60 (20.02, 37.18) 2.15
Moore 2008 Healthy participants Supine 100 17.80 (-5.50, 41.10) 0.46
Oguanobi 2012 Healthy participants Supine 62 3.70 (0.48, 6.92) 4.20
Quong 2016 Healthy participants Supine 73 11.00 (7.09, 14.91) 3.91
Rahiala 2001 Healthy participants Supine 20 13.00 (5.25, 20.75) 2.39
Richart 2009 Healthy participants Supine 105 17.60 (13.07, 22.13) 3.64
Sahli 2004 Healthy participants Supine 134 16.00 (15.52, 16.48) 4.97
Sahli 2004 Type I diabetics Supine 166 10.00 (9.45, 10.55) 4.96
Sahli 2004 Type II diabetics Supine 137 17.00 (16.16, 17.84) 4.93
Subtotal (I-squared = 97.1%, P = 0.000) 16.18 (13.38, 18.97) 40.54
Unclear
Koay 1985 Hospital inpatients Supine 15 13.00 (-5.66, 31.66) 0.69
Wilkes 2004 Hospital inpatients Unclear 45 23.30 (19.91, 26.69) 4.13
Yeragani 2007 Healthy participants Unclear 22 7.00 (-0.98, 14.98) 2.32
Yeragani 2007 Patients with anxiety Unclear 26 9.00 (-0.38, 18.38) 1.93
Yeragani 2007 Patients with CVD Unclear 72 10.00 (3.76, 16.24) 2.93
Subtotal (I-squared = 85.1%, P = 0.000) 12.83 (4.35, 21.31) 12.00
Overall (I-squared = 95.1%, P = 0.000) 16.95 (15.28, 18.61) 100.00
NOTE: Weights are from random effects analysis
-50
-25
0
25
50
Arm BP is higher
Ankle BP is higher

**FIGURE 2** Arm–ankle SBP difference in the general population ($n = 24$ studies). Mean SBP difference given in mmHg. BP, blood pressure; CI, confidence interval; CVD, cardiovascular disease; ED, emergency department.

simultaneously (18.3 mmHg, 95% CI 17.1–19.5 mmHg) or sequentially (16.1 mmHg, 95% CI 13.4–19.0 mmHg; Fig. 2). Overall heterogeneity was significant ($I^2 = 95.1\%$; $P < 0.001$) and was not reduced in subgroups examining simultaneous or sequential measurements. For DBP, there was no difference between arm and ankle BP (−0.3 mmHg, 95% CI −1.5–1.0 mmHg; Fig. 3). Once again this was unaffected by whether readings were taken simultaneously (−1.2 mmHg, 95% CI −2.8–0.3 mmHg) or sequentially (1.9 mmHg, 95% CI −3.9–7.7 mmHg), and there was significant heterogeneity across studies ($I^2 = 93.6\%$; $P < 0.001$).

## Calf/thigh–arm differences in supine position

Average calf SBP was higher than arm BP, but the mean difference was not as large as arm–ankle differences (10.1 mmHg, 95% CI 4.5–15.6 mmHg; $I^2 = 94.8$; $P < 0.001$; eFigure 1, online Appendix, http://links.lww.com/HJH/B26). There was no difference between arm and calf DBP (0.2 mmHg, 95% CI −1.5–1.8 mmHg; $I^2 = 99.1$; $P < 0.001$). There were not enough studies in similar populations to provide pooled estimates of the arm–thigh BP difference.

## Secondary outcomes

In patients with a history of CVD, ankle SBP was lower than arm BP (−33.3 mmHg, 95% CI −59.1 to −7.6 mmHg; Fig. 4), although there was significant variation depending on the disease type ($I^2 = 99.1\%$; $P < 0.001$). Focusing on patients with high risk of CVD did not affect the point estimates for arm–ankle SBP or DBP difference, compared with the general population, or reduce the overall heterogeneity observed (eFigure 2, online Appendix, http://links.lww.com/HJH/B26). Subgroup analyses by measurement device used for



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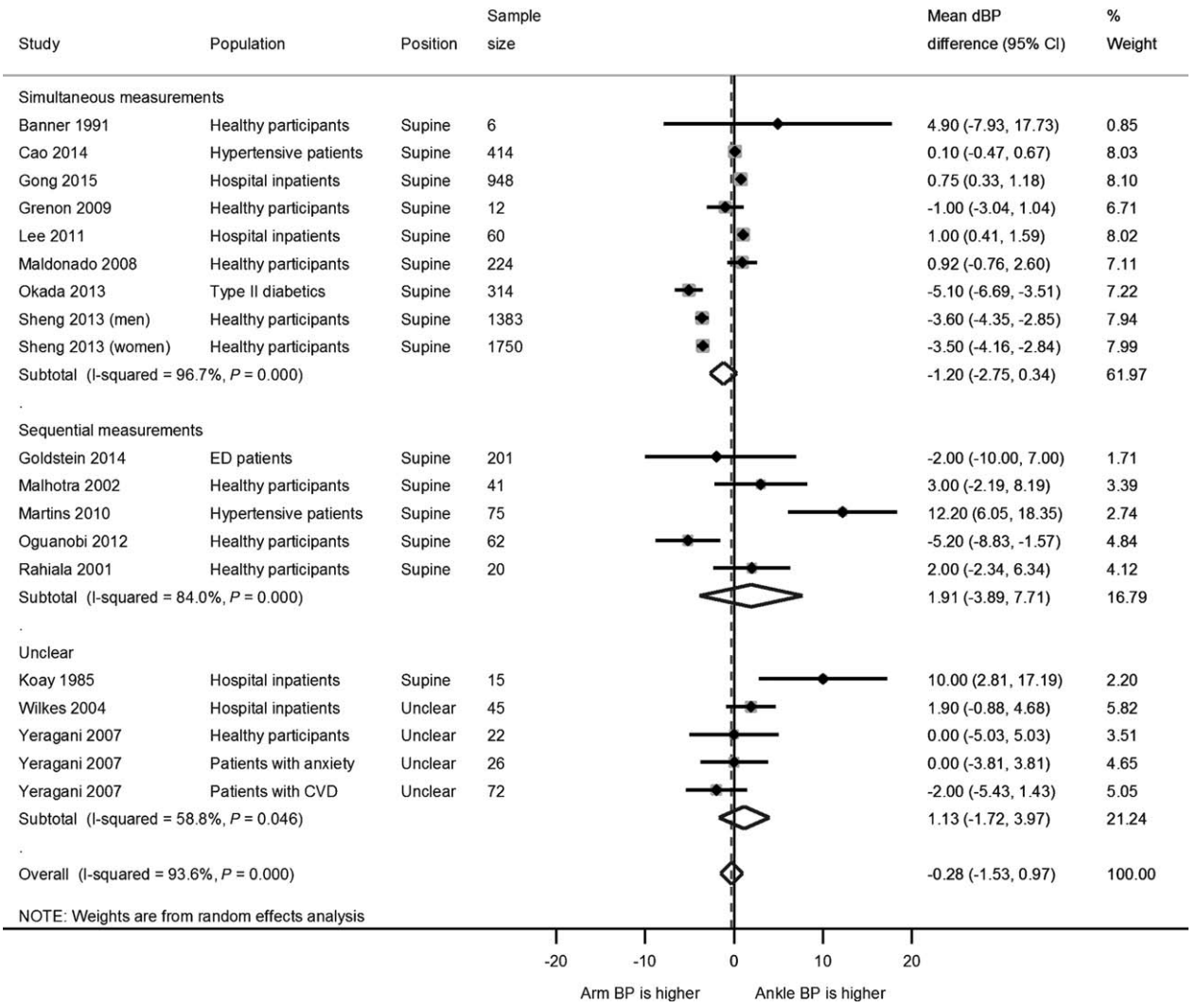
Study
Population
Position
Sample size
Mean dBP difference (95% CI)
% Weight
Simultaneous measurements
Banner 1991 Healthy participants Supine 6 4.90 (-7.93, 17.73) 0.85
Cao 2014 Hypertensive patients Supine 414 0.10 (-0.47, 0.67) 8.03
Gong 2015 Hospital inpatients Supine 948 0.75 (0.33, 1.18) 8.10
Grenon 2009 Healthy participants Supine 12 -1.00 (-3.04, 1.04) 6.71
Lee 2011 Hospital inpatients Supine 60 1.00 (0.41, 1.59) 8.02
Maldonado 2008 Healthy participants Supine 224 0.92 (-0.76, 2.60) 7.11
Okada 2013 Type II diabetics Supine 314 -5.10 (-6.69, -3.51) 7.22
Sheng 2013 (men) Healthy participants Supine 1383 -3.60 (-4.35, -2.85) 7.94
Sheng 2013 (women) Healthy participants Supine 1750 -3.50 (-4.16, -2.84) 7.99
Subtotal (I-squared = 96.7%, P = 0.000) -1.20 (-2.75, 0.34) 61.97
Sequential measurements
Goldstein 2014 ED patients Supine 201 -2.00 (-10.00, 7.00) 1.71
Malhotra 2002 Healthy participants Supine 41 3.00 (-2.19, 8.19) 3.39
Martins 2010 Hypertensive patients Supine 75 12.20 (6.05, 18.35) 2.74
Oguanobi 2012 Healthy participants Supine 62 -5.20 (-8.83, -1.57) 4.84
Rahiala 2001 Healthy participants Supine 20 2.00 (-2.34, 6.34) 4.12
Subtotal (I-squared = 84.0%, P = 0.000) 1.91 (-3.89, 7.71) 16.79
Unclear
Koay 1985 Hospital inpatients Supine 15 10.00 (2.81, 17.19) 2.20
Wilkes 2004 Hospital inpatients Unclear 45 1.90 (-0.88, 4.68) 5.82
Yeragani 2007 Healthy participants Unclear 22 0.00 (-5.03, 5.03) 3.51
Yeragani 2007 Patients with anxiety Unclear 26 0.00 (-3.81, 3.81) 4.65
Yeragani 2007 Patients with CVD Unclear 72 -2.00 (-5.43, 1.43) 5.05
Subtotal (I-squared = 58.8%, P = 0.046) 1.13 (-1.72, 3.97) 21.24
Overall (I-squared = 93.6%, P = 0.000) -0.28 (-1.53, 0.97) 100.00
NOTE: Weights are from random effects analysis
-20
-10
0
10
20
Arm BP is higher
Ankle BP is higher

**FIGURE 3** Arm–ankle DBP difference in the general population ($n = 16$ studies). Mean DBP difference given in mmHg. BP, blood pressure; CI, confidence interval; CVD, cardiovascular disease; ED, emergency department.

ankle measurements did not reduce the observed heterogeneity within groups (eFigure 3, online Appendix, http://links.lww.com/HJH/B26). No association was observed between arm–ankle BP difference and mean arm BP or age (Fig. 5).

## Sensitivity analyses

Sensitivity analyses were undertaken examining arm–ankle BP difference in the general population assuming fixed effects and found similar findings to the primary analyses (eFigures 4 and 5, online Appendix, http://links.lww.com/HJH/B26). Exclusion of studies deemed to be of moderate or low quality had no impact on the point estimates for arm–ankle BP difference, but did reduce the observed heterogeneity between studies making simultaneous comparisons, albeit remaining significant ($I^2 = 77.4\%$; $P = 0.001$; eFigures 6 and 7, http://links.lww.com/HJH/B26). Exclusion of studies which did not measure both systolic and diastolic pressures in the same patients had no impact on the main study findings (eFigure 8, http://links.lww.com/HJH/B26). Exclusion of studies which did not use auscultation or a validated upper arm device did not affect the point estimates for arm–ankle BP difference, but it did reduce the observed heterogeneity [$I^2 = 38.4\%$; $P = 0.150$ (systolic comparison) eFigure 9, http://links.lww.com/HJH/B26; $I^2 = 42.7\%$; $P = 0.175$ (diastolic comparison) eFigure 10, http://links.lww.com/HJH/B26]. Examining the difference in arm–ankle BP as a percentage of the arm BP gave similar findings to the primary analysis, with SBP in the ankle being 12.9% (95% CI 11.5–14.3%) higher than in the arm (eFigure 11, http://links.lww.com/HJH/B26).

# DISCUSSION

## Summary of findings

This is the first systematic review to examine studies comparing BP measured in the arm to measurements taken in the leg and provides average differences to guide interpretation in routine clinical practice. In a general population measured in a supine position, readings taken in the ankle were found to be between 16 and 18 mmHg higher than those taken in the arm, and this was unaffected by whether measurements were taken simultaneously or sequentially. These data suggest clinicians should consider



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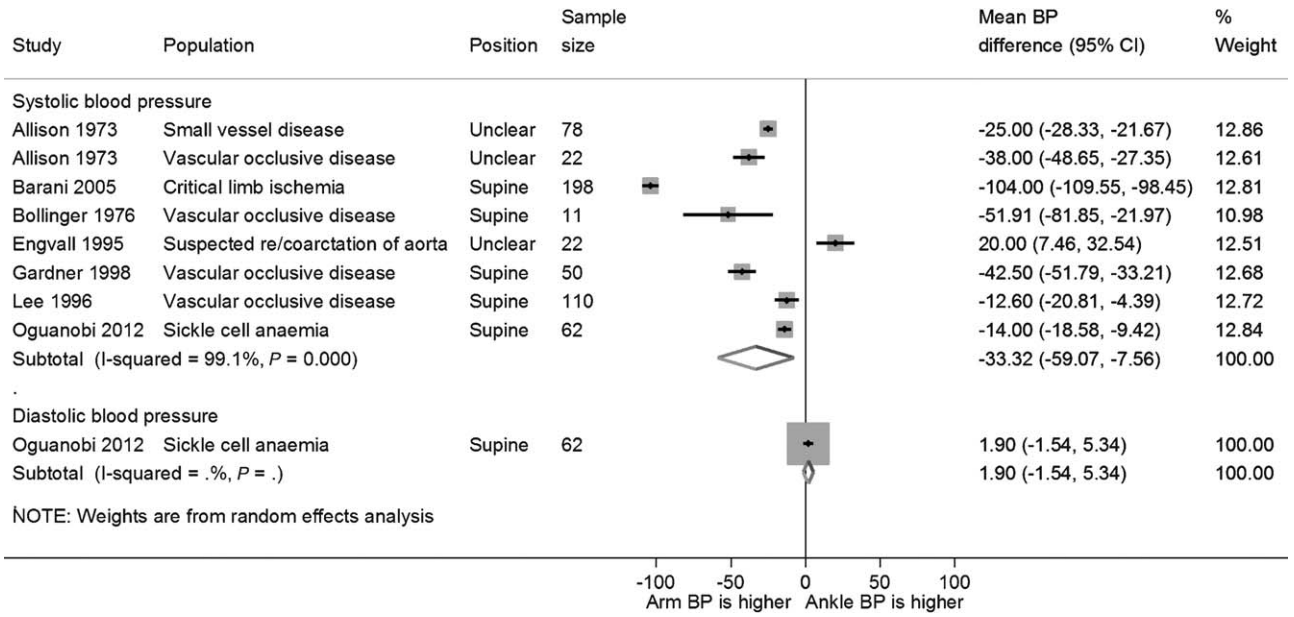
Study
Population
Position
Sample size
Mean BP difference (95% CI)
% Weight
Systolic blood pressure
Allison 1973 Small vessel disease Unclear 78 -25.00 (-28.33, -21.67) 12.86
Allison 1973 Vascular occlusive disease Unclear 22 -38.00 (-48.65, -27.35) 12.61
Barani 2005 Critical limb ischemia Supine 198 -104.00 (-109.55, -98.45) 12.81
Bollinger 1976 Vascular occlusive disease Supine 11 -51.91 (-81.85, -21.97) 10.98
Engvall 1995 Suspected re/coarctation of aorta Unclear 22 20.00 (7.46, 32.54) 12.51
Gardner 1998 Vascular occlusive disease Supine 50 -42.50 (-51.79, -33.21) 12.68
Lee 1996 Vascular occlusive disease Supine 110 -12.60 (-20.81, -4.39) 12.72
Oguanobi 2012 Sickle cell anaemia Supine 62 -14.00 (-18.58, -9.42) 12.84
Subtotal (I-squared = 99.1%, P = 0.000) -33.32 (-59.07, -7.56) 100.00
Diastolic blood pressure
Oguanobi 2012 Sickle cell anaemia Supine 62 1.90 (-1.54, 5.34) 100.00
Subtotal (I-squared = .%, P = .) 1.90 (-1.54, 5.34) 100.00
NOTE: Weights are from random effects analysis
-100 -50 0 50 100
Arm BP is higher
Ankle BP is higher

**FIGURE 4** Arm–ankle blood pressure difference in patients with a history of cardiovascular disease ($n = 7$ studies). Mean BP difference given in mmHg. BP, blood pressure; CI, confidence interval.

adding 15 mmHg to the systolic treatment threshold for hypertension (giving a threshold of 155/90 mmHg) when using ankle measurements rather than readings taken in the arm.

## Strengths and limitations

The current large systematic review followed a prespecified protocol (see online Appendix, http://links.lww.com/HJH/B26) and utilized a comprehensive search of seven relevant

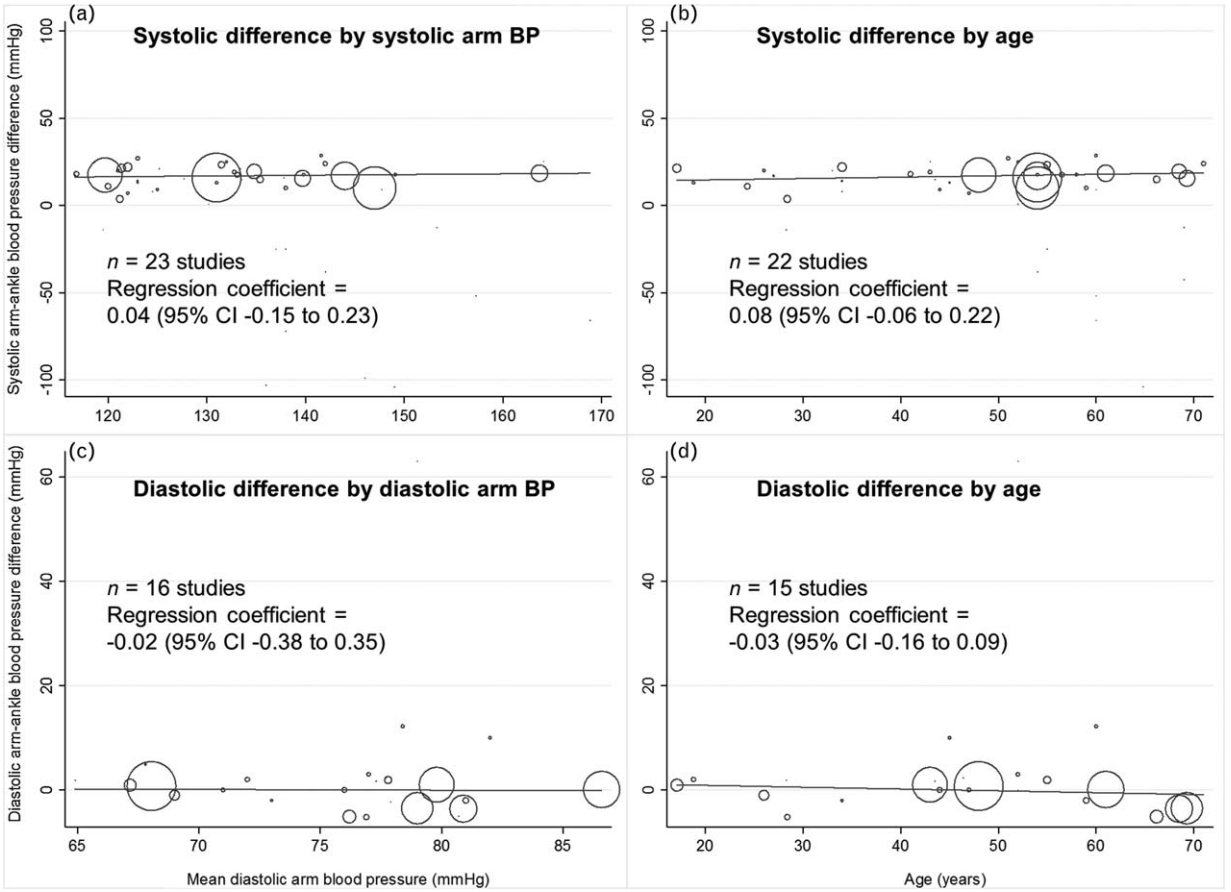
(a)
Systolic difference by systolic arm BP
n = 23 studies
Regression coefficient =
0.04 (95% CI -0.15 to 0.23)
Systolic arm-ankle blood pressure difference (mmHg)
(b)
Systolic difference by age
n = 22 studies
Regression coefficient =
0.08 (95% CI -0.06 to 0.22)
(c)
Diastolic difference by diastolic arm BP
n = 16 studies
Regression coefficient =
-0.02 (95% CI -0.38 to 0.35)
Diastolic arm-ankle blood pressure difference (mmHg)
Mean diastolic arm blood pressure (mmHg)
(d)
Diastolic difference by age
n = 15 studies
Regression coefficient =
-0.03 (95% CI -0.16 to 0.09)
Age (years)

**FIGURE 5** Meta-regression of arm–ankle blood pressure difference in the general population by mean arm blood pressure and age. BP, blood pressure; Moore *et al.* [6] excluded due to lack of data on mean arm blood pressure and age; Banner and Gravenstein [13] excluded due to lack of data on age.



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databases to capture all potential studies examining the difference between arm and leg BP. Predefined inclusion/exclusion criteria were applied to each article identified in the search and a total of 44 relevant articles were included in the final review. On the contrary, it was not possible to locate further potentially eligible articles, despite visiting the British Library to locate them. Other articles had to be excluded because they were written in non-English language and there were insufficient resources to translate them for screening. Despite this, the consistent direction and magnitude of differences observed in a large number of included articles suggest that even if some of these articles had provided relevant data, the overall findings of the study would have likely remained the same.

It was possible to pool data for meta-analysis in the current study, however there was significant heterogeneity across studies so caution should be exercised when interpreting the results. Subgroup and sensitivity analyses by CVD history, CVD risk, measurement method/device and methodological quality did not sufficiently explain the observed variation, although exclusion of studies not using auscultation or a validated upper arm device did reduce some the observed heterogeneity, suggesting this may have been a contributing factor. Although age has previously been shown to affect the magnitude of arm–ankle BP difference [5], meta-regression by age revealed no such association in the present data. Other factors contributing towards the observed heterogeneity might include the BP device and model used, number of readings taken and the observer making the measurement (e.g. doctor, nurse, researcher), all of which were likely to have varied across the included studies.

Since this study examined only aggregate data, it was not possible to study arm–leg BP difference at different BP levels for individual patients. However, meta-regression by mean arm BP, and sensitivity analyses of the arm–ankle difference as a percentage of the arm BP suggested no relationship exists. Although the aim of this study was to define the average arm–leg BP difference for occasions where measurement in the arm is not possible, we cannot rule out the possibility that such a difference would be greater in the absence of limbs, due to the effects of changing resistance and altered reflection points.

## Comparison with previous literature

Although there are many previous studies which have measured arm and leg BP in the same patient, most focus on estimating ankle–brachial index for detection of underlying vascular disease [19,20,30,32,47]. Few studies have set out to measure the arm–leg BP difference in the general population to aid interpretation of leg measurements in clinical practice. One study by Gong *et al.*[5], showed in 948 patients that BP was 17.4 mmHg (95% CI 16.7–18.1 mmHg) higher when measured in the ankle than when measured in the arm, findings which are consistent with the present review.

## Implications for clinical practice

Current clinical guidelines pay little attention to measurement of BP in the leg and there is no guidance on the most appropriate method of measurement [1]. The current study found no agreed measurement protocol for estimating leg BP across studies. Generally, older studies used Doppler probes and strain-gauge plethysmography techniques [15,17,18,28,42]. Newer studies using validated oscillometric sphygmomanometers found similar arm–leg BP differences to those using other devices [4,5,19], although the statistical heterogeneity across studies was reduced. When measuring arm–leg BP differences, for example in the assessment of peripheral vascular disease, the present data suggest similar differences can be observed using sequential vs. simultaneous methods. This approach is likely to be more clinically acceptable when assessing patients, particularly where resources limit the use of BP monitors capable of connecting to two cuffs. Previous studies suggest that like the arms, an interankle difference may be associated with an increased risk of mortality and so using readings from the leg which provides the higher value may be important [41].

The current study found the mean difference between leg and arm BP when measured in a supine position to be 17/0 mmHg (ankle) and 10/0 mmHg (calf). Using the traditional 140/90 mmHg threshold for hypertension [51], these differences translate into a diagnostic threshold of 155/90 mmHg for ankle BP and 150/90 mmHg for calf BP. This is in contrast to the 175 mmHg threshold previously suggested by Hietanen *et al.* [7], which was based on risk of subsequent cardiovascular morbidity and mortality. Since there are no trials of treatment based on leg BP, it is logical to use thresholds which are equivalent to those used for the arm readings, which are underpinned by a large body of evidence [52]. The slightly more conservative difference of 15 mmHg recommended here would ensure maximum sensitivity albeit with reduced specificity for true hypertension. The lack of difference in diastolic arm–leg BP appears to support the concept of pressure amplification: systolic pressure increases with greater distance towards the periphery, but there is little change in diastolic pressure. This may suggest caution is warranted in using oscillometric monitors optimized for analysing brachial pressure as the relationship between mean and systolic pressure may differ in the lower limb.

It should be noted that all BP readings examined in this study were taken in the supine position, whereas in previous BP lowering trials (which have established diagnostic thresholds), readings are usually taken in the sitting position [52]. It is unclear what impact this would have on the proposed thresholds, since some studies suggest arm BPs measured in the sitting position are higher than readings taken in the supine position [53,54], whereas others suggest no difference [54] or higher readings in the supine position [55,56]. Our sensitivity analyses suggest that BP measured in the ankle (in the supine position) was, on average, 12.9% higher than that in the arm (in the supine position); this would equate to an equivalent diagnostic threshold based on sitting readings of 158/90 mmHg, assuming the relative differences are the same in both positions. Given this debate, we recommend that physicians use the proposed threshold with caution, particularly when initiating new treatment in patients who are found to be close to the diagnostic threshold. In addition, given that ankle and calf BPs are likely to be significantly lower in patients with vascular occlusive diseases, it may be advisable that further



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investigation is considered in patients with apparently low ankle SBP readings, despite the presence of cardiovascular risk factors such as diabetes, renal disease or CVD.

For the assessment of leg BP alone (when no arm BP measurement is possible) the results from this review suggest that ankle BP measured in a supine position using the dorsalis pedis artery may be the most clinically appropriate leg measurement given the paucity of data in the arm/calf and arm/thigh comparisons. In addition, ankle measurements are less likely to cause discomfort than calf or thigh measurements and the cuff will be easier to fit, particularly in obese patients. Data from the primary studies included in this review did not consistently report the number of repeat readings taken in the ankle, with only 11/30 studies reporting this information at all (eTable 3, http://links.lww.com/HJH/B26). The vast majority of studies comparing arm–ankle BP took measurements in the ankle with the patient in the supine position, with a 5–10-min rest period prior to measurement.

Given the lack of detailed reporting on leg BP measurement methods, it is not possible to make further specific recommendations regarding measurement protocols. No oscillometric BP monitors have specifically been validated for leg measurements and the use of ambulatory readings for diagnosis will not be possible in patients who need to have leg BP measurements. The use of auscultation may present practical difficulties with placement of the stethoscope and use of Doppler 'return to flow' will only give a systolic reading. Further work should aim to determine the optimal leg BP measurement protocol to aid the clinical utility of this article's findings.

In conclusion, the current review is the first to provide empirical data for defining the difference between BP in the arm with BP measured in the ankle or calf. It suggests that in the general population, clinicians should expect systolic readings which are at least 15 mmHg higher than those taken in the arm in the supine position. A diagnostic threshold of 155/90 mmHg could therefore be used for diagnosing hypertension when relying on ankle measurements alone.

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### Conflicts of interest

There are no conflicts of interest.

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